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Effects of two dried forages, and a choice between them, on intake, growth and carcass composition in lambs of two breeds and their cross

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Abstract

The effects of forage type, breed type and sex on lamb growth and carcass composition, and their changes throughout growth, were measured. The three breed types were Scottish Blackface (no. = 31), Suffolk (no. = 28) and their reciprocal cross (no. = 30). The lambs were given ad libitum *a pelleted ryegrass alone, pelleted lucerne alone or a choice of both. Each lamb was scanned using X-ray computed tomography to measure the weights of fat, lean and bone in the carcass at three proportions of mature body weight (0·30, 0·45 and 0·65). Live weights and food intake data were recorded weekly. Average daily gains in live weight and carcass tissues, food intake and efficiency were calculated for each lamb between degrees of maturity. Relationships between weight and food intake were investigated using a Spillman function.*

Breed type had no effect on fat or lean proportion in the carcass but Scottish Blackface lambs had 1·04 times the carcass bone proportions of the Suffolk or crossbred lambs. Diet had no effect on carcass tissue proportions. The effect of sex on carcass composition changed with stage of maturity. Breed type and sex effects on intakes and gains in live weight and tissue weights were related to mature size differences. Scaling by (mature size)$^{0.73}$ did not fully remove these differences. There were no effects of breed type, sex or diet on efficiency. Lambs on ryegrass had lower intakes (0·878 as great) and slower growth (0·851 as fast) than those on lucerne or the choice treatment. The mean proportion of ryegrass in the choice diet was 0·366 (s.e. 0·0273); it increased slightly with time. There was no breed type by diet interaction for any of the variables examined. The Spillman function described growth well and showed that there were no effects of breed type, diet or sex on efficiency.

Keywords: *carcass composition, computed tomography, food preferences, forage, growth, sheep.*

Introduction

The decline in lamb consumption over the last few decades has been attributed at least in part to consumers' preference for leaner meat than that provided by a typical lamb carcass (Woodward and Wheelock, 1990). To better meet market requirements, producers need information on breed, food and management choices that will allow them to produce high quality lamb carcasses. Several previous studies have separately examined factors that may affect lamb carcass composition.

Between breeds much of the variation in carcass composition at a particular weight is accounted for by differences in mature size (Taylor *et al.*, 1989). It was found by Taylor *et al.* (1989), across the six domestic breeds of sheep used, that the proportion of fat in the carcass at the same calculated degree of maturity varied only between 247 g/kg for the Jacob and 317 g/kg for the Oxford Down. The values for the Welsh Mountain, Southdown, Finnish Landrace and Wiltshire Horn were between these. For these six breeds there was no relation between carcass fatness at a given degree of maturity and mature size. Butterfield *et al.* (1983) reported that their large mature size strain of Merino had 'slightly more' carcass fat than the small mature size strain at the same degree of maturity.

The evidence cited above comes from experiments where all of the breeds were treated in the same way. Level of feeding did not affect the extent to which a line of Suffolks, selected on an index to increase lean weight and decrease fatness at a particular age, was superior to its control in the level of fatness in the carcass (Lewis *et al.*, 2002). This was despite the fact that the extent to which selection had increased growth rate and efficiency decreased as the level of feeding decreased. There is little other evidence for or against the existence of breed by food interactions for carcass composition.

The present study is an extension of that of Lewis *et al.* (2004b) and uses the same two diverse breeds (Suffolk, a terminal sire breed, and Scottish Blackface, a hill breed) and their cross to represent a wide range of breed performance. The range of diets is extended to two dried forages, lucerne and ryegrass, and a choice between them.

As in Lewis *et al.* (2004b) X-ray computed tomography (CT) scanning was used to study carcass composition and its changes with growth. CT, as a non-destructive method, is particularly useful where measurements are needed over ranges of weights. Such data can be used to make comparisons between breeds and sexes at equal degrees of maturity in live weight, to remove at least in part the effects of differences in mature size and degree of maturity on the variables being examined (Taylor, 1980).

The objective of this study was to explore the effects of two forages and a choice between them, on the live performance and carcass composition of the lambs of two very different breeds and their crosses. The experiment was part of a series intended to investigate the possible presence of genotype by feeding interactions for domestic sheep breeds where the feeding used included concentrate diets given at different levels, dried forages and grazing different pastures.

Material and methods

The protocols used were similar to those fully described by Lewis *et al.* (2004b) and will be described only briefly here with the differences noted.

Management

Ewes of the Scottish Blackface (no. = 34) and Suffolk (no. = 32) breeds were mated to four rams of each breed to produce lambs that were purebred Scottish Blackface (B), purebred Suffolk (S) or either of the two crosses. Within a week of birth, lambs were offered free access to a creep food of high quality (Table 1). Lambs were weighed weekly from birth. On reaching target weights of proportionally 0·20 of estimated mature weight (Table 2) or 8 weeks of age, whichever came sooner, they were weaned. The estimates of mature weight for the two breeds and the cross are given in Table 2, which is taken from Lewis *et al.* (2004b).

At weaning, each lamb was allocated randomly to a feeding treatment within breed type, sex and half-sib sire family. Lambs on a given treatment were group penned and given the appropriate food. The feeding treatments used were pelleted lucerne (*Medicago sativa*) alone, pelleted ryegrass (*Lolium multiflorum*) alone, or both as a choice. The foods are described in Table 1. Lambs were gradually introduced to their feeding treatment during an adjustment period. On reaching a weight of approximately 1 kg heavier than their target weaning weight (Table 2), the lambs were placed in individual pens (2·93 m^2) in a slatted shed and given *ad libitum* access to their allocated food or foods. The food intake data used started at this point (start).

The one (for lambs offered a single food) or two (for lambs offered both foods) troughs provided for each

Table 1 *Ingredients and chemical composition of the foods used*

	Creep food	Ryegrass	Lucerne
Ingredient (g/kg)			
Barley	582·5		
Dried grass	200·0	970·0	
Dried lucerne	0·0		970·0
Hipro soya-bean meal	70·0		
Fish meal	60·0		
Molasses	50·0		
Mineral and vitamin mix	37·5	30·0	30·0
Chemical composition			
Dry matter (g/kg)	912	958	939
Crude protein (g/kg DM)	192	135	182
NDF (g/kg DM)†	225	493	449
AHEE (g/kg DM)†	32·6	32·3	35·5
Ash (g/kg DM)	75	103	103
NCGD (g/kg)†	780	654	576
Metabolizable energy (MJ/kg DM)	11·7‡	9·5§	8·3§

† NDF = neutral-detergent fibre; AHEE = acid hydrolysed ether extract; NCGD = neutral cellulase gamanase digestibility.
‡ Predicted from 0·014 NCGD + 0·025 AHEE (Thomas *et al.*, 1988), which is germane to foods comprised of several ingredients.
§ Predicted from 0·0154 NCGD − 0·59 (Givens *et al.*, 1992), which is germane for a food comprised of a single forage.

Table 2 *Target weights (kg) for male (M) and female (F) lambs of each breed and their cross*

Stage of maturity	Breed type‡					
	B		X		S	
	M	F	M	F	M	F
Weaning	18·0	14·0	23·0	17·5	26·0	20·0
0·30†	27·0	20·5	34·0	26·0	39·0	30·0
0·45†	40·5	31·0	51·5	39·5	58·5	45·0
0·65†	58·5	45·0	74·0	57·0	84·5	65·0
Maturity	90·0	69·0	114·0	88·0	130·0	100·0

† Proportions of maturity in live weight at which lambs were computed tomography (CT) scanned.
‡ Breed types were purebred Scottish Blackface (B), purebred Suffolk (S) and both of their reciprocal crosses (X).

lamb were filled twice daily with sufficient food to ensure its *ad libitum* availability. A pelleted vitamin and mineral supplement was added to the food at the level of 0·03 of the average amount of food offered. All lambs also received 75 g of hay (crude protein 72 g/kg dry matter (DM); modified acid-detergent fibre 391 g/kg DM) daily. The allocation of the 89 lambs used to treatment is shown in Table 3. As no differences in performance traits between the two reciprocal crosses could be demonstrated, the two groups were combined as 'the cross' (X).

Measurements
The sheep were weighed each week on Thursday. Food intake over the week, excluding hay, was also recorded on that day. For lambs on the choice treatment the intakes of both foods were recorded separately. On reaching 0·30, 0·45 and 0·65 of estimated mature weight, each lamb was scanned using CT. Each lamb was scanned in cross-section at three sites: near the shoulder (sixth thoracic vertebra; TV6), along the loin (second lumbar vertebra; LV2) and at the hind leg (ischium, ISC). Areas of fat, lean and bone were derived from the scans at each of these three body sites.

Derived variables
Weights of fat, lean and bone in the carcass were estimated from the tissue areas given by the CT scans, and live weight. The prediction equations used were those in Table 4 of Lewis *et al.* (2004b). Carcass weight was calculated as the sum of the predicted weights of fat, lean and bone in the carcass. Proportions of each tissue in the carcass (g/kg) for each lamb were then calculated at each scanning event. Average daily gains of each tissue between the adjacent scanning events were obtained for each lamb.

The data on intake and live weight were used to calculate average daily rates of gain (ADG; g/day) and food intake (ADI; g/day) between successive degrees of maturity (start to 0·30, 0·30 to 0·45, and 0·45 to 0·65). Food efficiency was calculated as EFF = 1000 × (ADG/ADI) g/kg. For the lambs on the choice food treatment, total food intake was used to calculate ADI. The proportion of total intake as ryegrass was calculated from the intakes of the two foods.

Statistical methods
In preliminary analyses, the residual maximum likelihood procedure (REML, Genstat 5 Committee, 2001) was used to fit a general linear model (GLM) to describe the derived variables. REML was used, as the data were unbalanced for some of the fixed effects tested. Litter size at birth (1, 2, or 3 and more), rearing type (single or twin), weaning category (weight or age based), dam age (2, 3 or 4 years), lambing difficulty score (assistance at lambing was required or not), and day of birth (as a linear covariate) were included in the model as fixed effects. Birth weight was included in the model as the deviation of an observation from the relevant breed type-sex mean, as a linear covariate. Treatment effects of breed, sex and food type were also included. None of the fixed effects, apart from the treatments, explained substantial amounts of variation in any of the variables, and significance at $P < 0.05$ was rare. In view of these results only the treatment effects and their interactions were included in further analyses.

As repeated measurements of CT tissue weights were taken on the same individuals at the three proportions of mature weight, residuals of these measurements may have been correlated. A repeated measures analysis of tissue proportions was used to test this possibility using an ante-dependence, order 1 model for correlation within animal across the two degrees of maturity (Genstat 5 Committee, 2001).

Table 3 *Numbers of male (M) and female (F) lambs in each treatment group*

Food†	Breed type‡					
	B		X		S	
	M	F	M	F	M	F
Ryegrass	6	5	4	7	7	4
Lucerne	5	5	5	5	5	4
Choice	5	5	3	6	6	2

† As described in Table 1.
‡ As described in Table 2.

This analysis allowed the effect of degree of maturity on tissue proportions, and the interaction of this with the treatment effects, to be identified. The same analysis was also carried out for ADG, ADI and EFF as recorded for the three intervals between the start of feeding treatments and the three scanning events.

Heterosis. Crossbred lambs are expected to be more heterozygous than their purebred parental breeds. The GLM model of Lewis *et al.* (2004b) was used to test for heterosis in the variables being examined here. The model was:

$$y_{ijkmn} = \mu + f_i + h_j + s_k + d_m + sd_{km} + \beta(w_{ijkmn} - \bar{w}) + \varepsilon_{ijkmn} \quad (1)$$

where y_{ijkmn} is the value of the derived variable for lamb n ($n = 1, 2, 3, \ldots, 89$) that was on diet f ($i = 1, 2, 3$) and of sex h ($j = 1, 2$), with a sire of breed s ($k = 1, 2$) and a dam of breed d ($m = 1, 2$). The linear regression of the derived value on birth weight (w_{ijkmn}), where birth weight was expressed as a deviation from the mean birth weight of the lamb's sex and breed type (S, B or X) combination ($\bar{w}$), was also included in the model. β is the regression coefficient, μ the overall mean and ε the residual error. A significant interaction between sire and dam breed (sd_{km}) would indicate heterosis.

Carcass composition. It was expected that breed and sex effects on composition at a given degree of maturity, if present at all, would be small. Composition was also expected to change systematically with degree of maturity in weight, defined as $u_t = W_t/A$, where W_t is weight at time t and A is asymptotic or mature weight.

Two descriptive models were used. Butterfield *et al.* (1983) proposed that (I/I_m) would be related to (T/T_m) by a quadratic equation of the form:

$$(I/I_m) = q(T/T_m) + (1 - q)(T/T_m)^2 \quad (2)$$

where I and I_m are the weights of a component at a time or at maturity, and T and T_m are the shorn full live weights at a time or at maturity. A value of $q < 1$ indicates a late maturing component relative to that of the shorn full live weight, and a value of $q > 1$ indicates an early maturing component. Our first model followed from an algebraic development of this. It was fitted as

$$y_{ijkn} = \mu + f_i + g_j + h_k + cu_n + du_n^2 + \varepsilon_{ijkn} \quad (3)$$

where y_{ijkn} is the proportion of fat, lean or bone for lamb n ($n = 1, 2, 3, \ldots, 89$) on food f ($i = 1, 2, 3$), of breed type g ($j = 1, 2, 3$) and of sex h ($k = 1, 2$) where u is stage of maturity in live weight, μ the overall mean and ε the residual error. The model allows for changes in a proportion to be other than linear with u through the quadratic term. When $d = 0$ the sign of the coefficient of c indicates whether a tissue is early maturing ($c < 0$) or late maturing ($c > 0$) in relation to live weight. When the value of d is not zero then the interpretation depends on the numerical values of both c and d, and is no longer necessarily simple.

The second model made composition change with degree of maturity in weight (u), raised to a power b. The allometric form fitted was (Emmans, 1988):

$$y_{ijkn} = \mu + f_i + g_j + h_k + au_n^b + \varepsilon_{ijkn} \quad (4)$$

where y_{ijkn} is the proportion of fat, lean or bone for lamb n ($n = 1, 2, 3, \ldots, 89$) on food f ($i = 1, 2, 3$), of breed type g ($j = 1, 2, 3$) and of sex h ($k = 1, 2$) where u is stage of maturity, μ the overall mean and ε the residual error. The coefficient a is the linear regression of the tissue proportion on degree of maturity in weight. The allometric coefficient b indicates whether a tissue is early maturing ($b < 0$) or late maturing ($b > 0$) in relation to live weight.

Weight by cumulative food intake. As there was no *a priori* reason to expect the sheep on any of the three treatments to grow either at their potential, or at a fixed proportion of this, the weight by time data were not used to estimate the values of the parameters of any growth function. However, weight was plotted against cumulative food intake for all of the 12 single food treatments (3 breed types $\times$ 2 sexes $\times$ 2 foods) to estimate the values of the parameters of the Spillman function (Lewis *et al.*, 2002 and 2004a). The form is

$$W = W_0 + (A - W_0)[1 - \exp(-k\,F)] \quad (5)$$

where F is cumulative food intake (kg) from the start of treatment, and A (the asymptotic weight) and k are the parameters to be estimated. It was found that the estimates of A and k were highly correlated so the values of the lumped parameter ($A\ k$) are also reported. To avoid bias, the data used continued only to the time when the first lamb on a treatment reached the end of its recording period.

Results

There was a significant effect of heterosis on ADG and ADI across the trial with cross lambs growing 1·08 as fast ($P < 0·01$) and eating 1·07 ($P < 0·001$) as much as the average of the pure breeds. Crossbred lambs also gained fat weight 1·08 ($P < 0·01$), and bone weight 1·05 ($P < 0·05$), times as fast as the average of the pure breeds. Although heterosis was not important across the trial period for carcass

Table 4 *Least-squares means of carcass weights (kg) at each stage of maturity for breed and sex†*

Stage of maturity‡	Breed type§ B		X		S	
	M	F	M	F	M	F
0·30	9·40	6·65	12·3	8·82	15·2	10·4
0·45	14·0	10·9	20·1	15·1	25·0	18·2
0·65	22·2	17·3	30·5	24·0	37·9	28·9

† M = male; F = female.
‡ Proportions of maturity in live weight at which lambs were computed tomography (CT) scanned.
§ As described in Table 2.

composition, there were significant effects of heterosis for fat content at 0·45 mature weight ($P < 0·05$) and for lean content at 0·45 and at 0·65 mature weight ($P < 0·05$). The crossbred had 1·07 as much fat, and 0·975 as much lean, as the average of the two pure breeds at these points.

Carcass composition. The relationship between maturity level and carcass weight is provided in Table 4. As there were no significant interactions between the treatment factors of diet, breed and sex with regards to tissue proportions, main effects are shown in Table 5. The repeated measures analysis showed that there was no effect of diet on carcass composition. Breed significantly affected only the proportion of bone in the carcass ($P < 0·05$); Scottish Blackface lambs had higher carcass bone proportion than Suffolk lambs with the cross lambs intermediate.

The effect of sex on carcass composition varied with degree of maturity ($P < 0·05$). When at 0·30 and 0·45 mature, female lambs had lower fat proportion (0·76 and 0·93 as great, respectively), higher lean proportion (1·02 and 1·01, respectively) and higher bone proportion (1·11 and 1·06, respectively) than male lambs. These differences had disappeared by the time the lambs were 0·65 mature.

The allometric function showed that fat was late maturing ($b = + 1·0163$) and bone was early maturing ($b = -0·6578$). These maturing patterns were in the expected directions. The allometric function also showed lean to be early maturing ($b = -0·2084$), although to a lesser extent than bone. The values of the coefficients of the quadratic function also showed that fat was late maturing since d was not significantly different from zero and c had a large positive value. However no definite conclusions could be reached from the values of the coefficients of the quadratic function for either lean or bone, as

Table 5 *Least-squares means of tissue proportions (g/kg) at each stage of maturity, and across maturity levels (from repeated measures analyses)†*

Treatment effects	Stage of maturity 0·30 Fat	Lean	Bone	0·45 Fat	Lean	Bone	0·65 Fat	Lean	Bone	Repeated measures means Fat	Lean	Bone
Breed‡												
B	128	635	237	221	586	193	336	507	157	229	576	195
X	136	631	233	252	567	181	352	497	151	247	565	188
S	136	635	228	251	576	173	346	510	144	245	573	182
Max s.e.d.	8·68	5·64	5·07	8·62	6·70	3·24	8·74	7·00	2·59	7·69	5·67	2·83
Diet§												
Ryegrass	130	635	235	241	576	183	338	512	150	237	574	189
Lucerne	126	638	236	236	579	185	343	504	153	235	574	191
Choice	144	628	228	247	574	179	353	498	149	248	567	185
Max s.e.d.	8·70	5·65	5·08	8·65	6·72	3·24	8·76	7·02	2·60	7·71	5·67	2·82
Sex‡												
F	115	640	245	233	580	187	344	505	151	231	575	194
M	152	627	221	250	573	177	345	505	150	249	568	183
s.e.d.	6·88	4·47	4·02	6·84	5·32	2·57	6·93	5·55	2·06	6·10	4·50	2·24

† Stage of maturity significantly affected fat, lean and bone proportions ($P < 0·001$) but diet had no effect on tissue proportions. Breed was important only for bone proportion ($P < 0·001$) and sex had effects on fat proportion ($P < 0·001$) and lean and bone proportions ($P < 0·05$). There were significant interactions between stage of maturity and sex for fat ($P < 0·001$), lean ($P < 0·05$) and bone ($P < 0·001$) proportions.
‡ As described in Table 2.
§ As described in Table 1.

the values for d were significantly different from zero.

Figures 1, 2, and 3 show the changes in fat, lean and bone proportions over time as modelled by the two functions. The data shown are averaged across breed, diet and sex, as these did not have any large effect on composition at a degree of maturity in weight (Table 5). The fit of the functions was good, and very similar for the two functions for fat and bone. For lean the fit of the allometric function to the data was less good than that of the quadratic function between 0·30 and 0·65 mature weight.

Live performance. Average daily gains in live weight, average daily food intakes and food efficiency are shown in Table 6. Rates of gain in live weight and intake increased with the mature size of the three breed types and two sexes as anticipated. Intake changed proportionately with stage of maturity in a similar way for all groups. Intake from the start of treatment to 0·30 was 0·62, and from 0·45 to 0·65 was 1·30, times as great as that from 0·30 to 0·45. No effects of breed or sex on efficiency were found by the repeated measures analysis.

Diet had no overall effect on efficiency but significantly affected both average daily gains and intakes. Lambs on lucerne grew faster and ate more food than those on ryegrass. Lambs on the choice diet had similar gains and intakes to lambs on lucerne across the trial period. No breed by food interaction was present for growth rates, intakes or efficiencies.

Diet composition. The mean proportion of ryegrass in the diets selected by the sheep given a choice was 0·366 (s.e. 0·0273) over the trial period. It was significantly less ($P < 0{\cdot}001$) than the proportion of 0·5 that would be expected by chance. Of the 29 lambs given a choice, 24 ate less ryegrass than lucerne. The proportion of ryegrass in the selected diet varied little with time but did show a weak ($r = 0{\cdot}638$, $P < 0{\cdot}05$) tendency to increase with time as seen in Figure 4.

Rates of gain of tissues

Table 7 shows average daily gain in fat, lean and bone between CT scanning events. Breed and sex significantly affected gains in weights of all tissues for both intervals as expected. There was a significant effect of diet on rates of tissue gains between 0·30 and 0·45 mature weight where lambs on ryegrass gained fat, lean and bone weights slower than lambs on lucerne or the choice diet. The lower gains in fat weight for lambs on ryegrass compared with lucerne or the choice diet continued into the interval between 0·45 and 0·65 mature weight. However, there was no significant difference in daily gains of lean or bone in this later interval.

Spillman analysis

Table 8 and Figure 5a and b show the estimates of parameters and curves generated by the Spillman function for lambs on ryegrass and lucerne. As expected, estimates of A and k were very highly negatively correlated (around −0·988) and the lumped parameter $A\,k$ gave a more robust descriptor of lamb growth by cumulative food intake. The fit of the Spillman function was good with residual standard deviations of between 0·151 and 0·568 kg (Table 8).

Discussion

Carcass composition. CT scanning was used to predict lamb carcass composition as in Lewis *et al.* (2004b) who discussed the merits of this technique in studies of this nature. It is generally accepted that variation between sheep breeds in carcass composition at a given weight can largely be accounted for by breed differences in mature weight. However, at the same degree of maturity in live weight, there may still be differences in carcass composition. McClelland *et al.* (1976) found that the feral Soay was much leaner at the same degree of maturity than were the three domestic breeds considered. Taylor *et al.* (1989) found that both the Soay and a feral goat were leaner than the six domestic breeds they used at the same degree of maturity.

It is less clear that there are real differences in carcass composition between domestic breeds of sheep and, if so, how these are related to differences in mature size. Across their six domestic breeds Taylor *et al.* (1989) found little difference in carcass fatness, and any difference present was not correlated with mature size. Butterfield *et al.* (1983) compared two strains of Merino that had been selected for different wool characteristics. The strain that happened to be of larger mature size also happened to be slightly fatter at the same degree of maturity. Gaili (1992) found little difference in carcass composition between three breeds of sheep from Saudi Arabia. There is an indication in the literature that the Texel, as a terminal sire, may give leaner carcasses than others may in crossbred lambs (Wolf *et al.*, 1980; Kempster *et al.*, 1987). Wood *et al.* (1980) found differences between breeds in carcass fatness at the same carcass weights, but concluded that these 'seemed to be related to mature body size'. Using the same breeds as in this study (Scottish Blackface, Suffolk and the cross between them) offered concentrate foods, Lewis *et al.* (2004b) also found that there were no breed differences in carcass

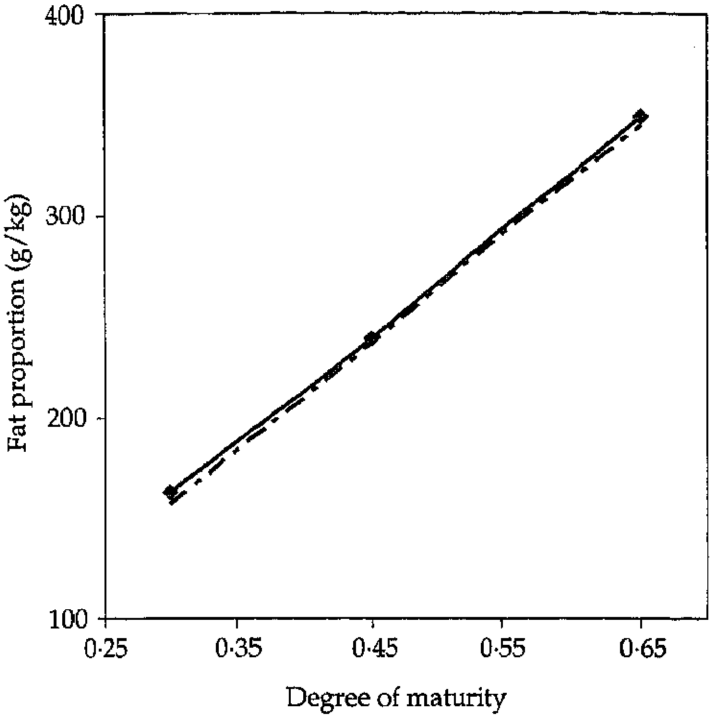

Figure 1 Change in fat proportion, p_f with increasing degree of maturity (u) as modelled by the quadratic ($p_f = 26 + 422u + 116u^2$) and allometric ($p_f = 6{\cdot}282\ u^{1{\cdot}016}$) functions. The fit of the quadratic (——) and allometric (–·–·–) function is shown. The least-squares means for fat proportion (◆) when lambs were 0·30, 0·45 and 0·65 mature are also plotted (s.e. 6·18 g/kg).

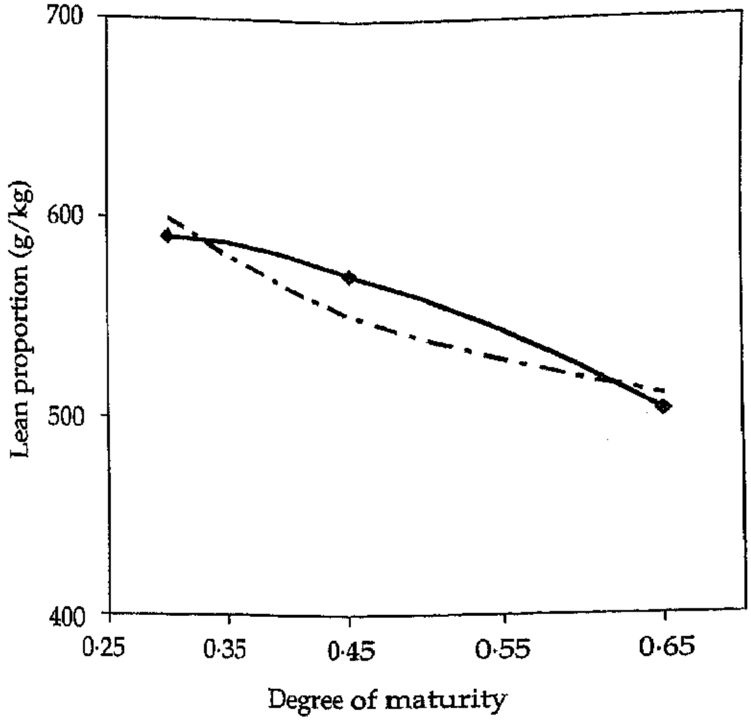

Figure 2 Change in lean proportion, p_l with increasing degree of maturity (u) as modelled by the quadratic function ($p_l = 543 + 348u - 613u^2$) and allometric ($p_l = 6{\cdot}146\ u^{-0{\cdot}208}$). The fit of the quadratic (——) and allometric (–·–·–) function is shown. The least-squares means for lean proportion (◆) when lambs were 0·30, 0·45 and 0·65 mature are also plotted (s.e. 4·95 g/kg).

Table 6 *Least-squares means of gain in live weight (ADG; g/day), daily food intake (ADI; g/day) and food efficiency (EFF; g/kg) between stages of maturity, and across maturity levels (from repeated measures analyses)*†

Treatment effects	Start‖ to 0·30 ADG	Start‖ to 0·30 ADI	Start‖ to 0·30 EFF	0·30 to 0·45 ADG	0·30 to 0·45 ADI	0·30 to 0·45 EFF	0·45 to 0·65 ADG	0·45 to 0·65 ADI	0·45 to 0·65 EFF	Repeated measures means ADG	Repeated measures means ADI	Repeated measures means EFF
Breed‡												
B	176	954	189	260	1661	157	229	2128	103	221	1611	150
X	230	1447	164	346	2223	159	297	2902	102	290	2190	142
S	250	1573	160	378	2512	155	330	3289	100	319	2457	138
Max. s.e.d.	14·49	86·90	12·74	12·26	66·80	9·02	16·00	63·36	4·15	8·45	36·19	5·19
Diet§												
Ryegrass	188	1186	162	297	2007	149	254	2537	100	246	1909	136
Lucerne	227	1315	175	335	2287	149	309	2959	104	289	2185	143
Choice	240	1473	176	353	2103	174	294	2913	101	296	2163	151
Max. s.e.d.	14·53	87·12	12·77	12·29	66·97	9·04	16·04	13·53	4·52	8·46	36·24	5·15
Sex‡												
F	184	1124	172	293	1831	164	257	2460	104	244	1804	147
M	253	1525	170	363	2434	150	314	3146	100	310	2368	140
s.e.d.	11·50	68·95	10·10	9·72	53·00	7·16	12·69	50·27	3·58	6·71	28·71	4·12

† Breed, diet, sex and maturity interval affected ADG and ADI ($P < 0{\cdot}001$) and there were interactions of breed and sex with maturity interval for ADI ($P < 0{\cdot}01$). Stage of maturity ($P < 0{\cdot}001$) was important for EFF.
‡ As described in Table 2.
§ As described in Table 1.
‖ Start is when recording of food intake data began after the period of adjustment to the food treatment and corresponds to an average maturity of 0·22 mature weight.

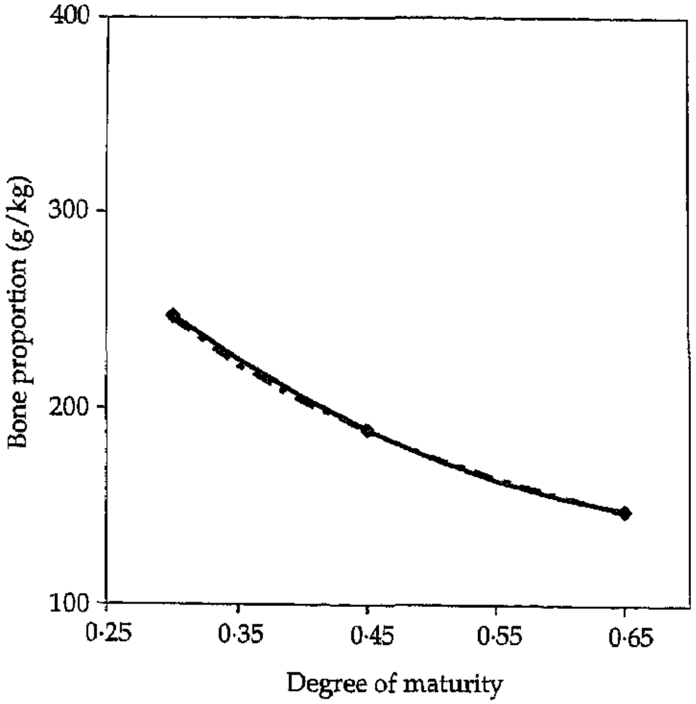

Figure 3 Change in bone proportion, p_b with increasing degree of maturity (u) as modelled by the quadratic function ($p_b = 431 + 771u - 515u^2$) and allometric function ($p_b = 4{\cdot}707\ u^{-0{\cdot}658}$). The fit of the quadratic (——) and allometric (—–·–) function is shown. The least-squares means for bone proportion (◆) when lambs were 0·30, 0·45 and 0·65 mature are also plotted (s.e. 3·16 g/kg).

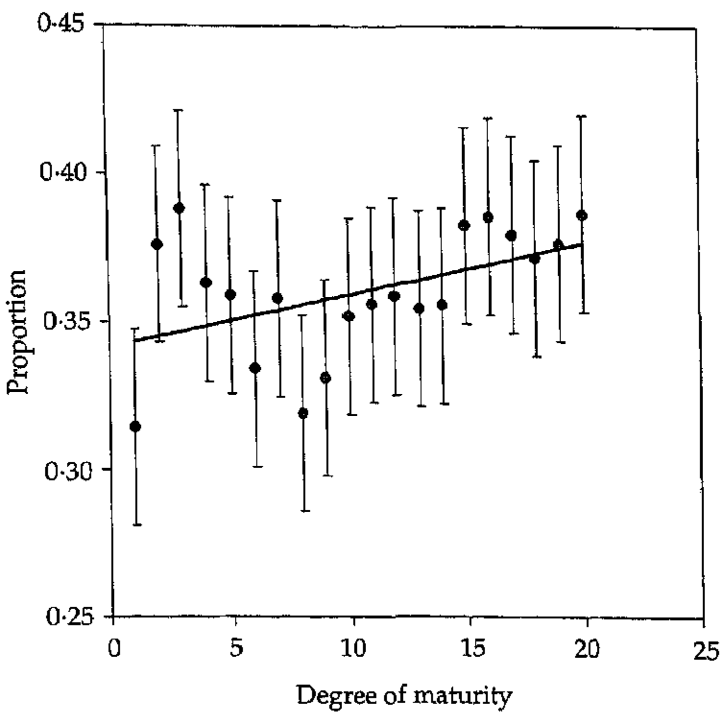

Figure 4 Average weekly proportion of ryegrass in the diet selected by lambs on the choice treatment (G) from the start of the experiment until the first lamb finished the experiment (W, weeks), where G = 0·342 + 0·002 W.

composition in lambs compared at the same degree of maturity. This is despite these breeds traditionally occupying very different sectors of the sheep industry and having different genetic selection backgrounds. The results reported here also show very little difference between these breeds in carcass composition at equal degrees of maturity. In contrast to previous studies however, the Scottish Blackface was found here to have a higher carcass bone content than Suffolk lambs. On closer examination of the results of Lewis *et al.* (2004b) it was found that the carcass of the Scottish Blackface had a higher bone content than the Suffolk on the more bulky food used, but not on the high quality food. It may be that a difference in bone content between these breeds is only apparent on a lower quality diet.

The similarities in the results of breed comparisons between the present study and that of Lewis *et al.* (2004b) cannot be taken simply to add weight to the evidence that the characteristics shown can properly be attributed to breed. This is because the lambs in the two studies had all their sires and approximately 60% of their dams in common. However, the fact that the lambs had a large proportion of their genes in common enables food differences and their interactions with breed to be attributed more reliably to food effects alone, although there may have been environmental variation between the years in which the two studies were conducted.

In general the evidence is that females are fatter than males at maturity (Taylor *et al.*, 1989). Wylie *et al.* (1997) and Lewis *et al.* (2002) also found that females were fatter over a range of degrees of maturity. In contrast, both Thompson *et al.* (1985) and Lewis *et al.* (2004b) found that males were fatter than females at a low degree of maturity. Those two studies also found that, as the lambs grew towards maturity, females became fatter than males with the sexes being of equal fatness at around 0·50 mature. In this experiment the two sexes attained equal fatness by 0·65 of mature weight. The results of this study give further evidence that male lambs may be fatter than females early in growth. The point at which they become equal in fatness, and thereafter are less fat, is affected by the conditions of the experiment but for reasons that are not clear.

There were no significant differences in carcass composition between the three feeding treatments used at any degree of maturity (Table 5). This is in contrast to the results of Lewis *et al.* (2004b) who found, with the two diverse concentrate foods (metabolizable energy (ME) values of 6·4 and 11·7 MJ/kg DM) that they used, large differences in carcass composition. They also found an interaction

Table 7 *Least-squares means of average gains (g/day) in tissue weights between stages of maturity at which computed tomography (CT) scanning took place*

Treatment effects	Maturity interval 0·30 to 0·45			Maturity interval 0·45 to 0·65		
	Fat	Lean	Bone	Fat	Lean	Bone
Breed type‡						
B	41·18	53·80	12·36	56·06	38·14	9·83
X	68·15	76·60	16·91	76·95	54·14	14·19
S	80·65	95·84	18·61	91·63	69·05	16·19
Max. s.e.d.	2·382	3·459	1·210	3·551	3·308	1·250
Diet§						
Ryegrass	56·80	67·36	14·39	64·67	51·12	11·84
Lucerne	65·29	77·93	16·73	80·37	56·70	14·45
Choice	67·88	80·97	16·77	79·59	53·51	13·92
Max. s.e.d.	2·388	3·468	1·213	3·560	3·316	1·253
Sex‡						
F	56·97	69·82	14·58	71·43	50·08	12·15
M	69·67	81·01	17·34	78·33	57·47	14·66
s.e.d.	1·890	2·744	0·960	2·818	2·624	0·992
Significance of effects						
Breed	***	***	***	***	***	***
Diet	***	***	*	***		
Sex	***	***	**	*	**	**

‡ As described in Table 2.
§ As described in Table 1.

between breed and the food type for ADG, ADI and EFF ($P < 0{\cdot}05$). In the present study, the lambs of all of the three breed types grew faster on lucerne than on ryegrass with no significant breed by food interactions. It seems that at the low levels of ME in the dried forages used, the extra protein in the lucerne was of no benefit in reducing carcass fatness.

As none of the treatment factors had consistent effects on the pathways to maturity of the different tissues, overall changes with degree of maturity could be considered. Both the quadratic and allometric functions described carcass composition well over the range of the data for fat and bone (Figures 1, 2 and 3). For lean, the quadratic function fitted the data better and was more sensible. The allometric function produced meaningful coefficients for all tissues in the directions expected and thus provides a stable model of carcass composition change.

Live performance

The large differences between breeds and sexes in the absolute rates of growth and food intake, seen in Table 6, are broadly in line with those expected from the differences in mature size presented in Table 2 (Thonney *et al.*, 1987). When scaled to $A^{0{\cdot}73}$ (Taylor, 1980), effects of breed ($P < 0{\cdot}001$) and sex ($P < 0{\cdot}05$) on both ADG and ADI were reduced, but still present. The Scottish Blackface had both a lower scaled ADG (9·11) than the Suffolk (9·97) and cross lambs (9·99) (s.e.d. 0·288), and a lower scaled ADI (66·0) than the Suffolk (76·7) and cross lambs (75·3) (s.e.d. 1·25). Females compared with males had a lower scaled ADG (9·49 *versus* 9·89; s.e.d. 0·235) and a lower scaled ADI (67·7 *versus* 75·6; s.e.d. 0·991). Despite breed and sex having large effects on absolute, and scaled, gains and intakes, there were no breed or sex effects on food efficiency. This is in agreement with results of previous studies (McClelland *et al.*, 1973; Butterfield *et al.*, 1983; Thompson and Parks, 1983; Thonney *et al.*, 1987; Lewis *et al.*, 2004b).

Food efficiency did not differ between the two forages used and this may have made it difficult for breed by food interactions to be observed. Lewis *et al.* (2004b) used foods that had large effects on gains, intakes and efficiency and also found important breed by food interactions for these traits. It is likely that the food types used need to produce different levels of performance if the Suffolk and the Scottish Blackface are to demonstrate interactions with those foods.

Table 8 *Values of the parameters of the Spillman function* $W = W_0 + (A-W_0)\,[1-exp(-k\,F)]$ *for lambs on the two single foods*†

Breed‡	Food§	Sex‡	No.‖	*A* (kg)	*k*	*A k*	Residual s. d. (kg)
B	Ryegrass	F	5 (20)	55·23	0·005966	0·3295	0·324
		M	6 (21)	73·54	0·004088	0·3006	0·242
	Lucerne	F	5 (18)	57·57	0·005487	0·3159	0·364
		M	5 (21)	80·52	0·003439	0·2770	0·485
X	Ryegrass	F	7 (21)	73·40	0·003718	0·2729	0·151
		M	4 (23)	99·21	0·002660	0·2639	0·405
	Lucerne	F	5 (20)	77·76	0·003663	0·2848	0·368
		M	5 (21)	96·15	0·003126	0·3005	0·395
S	Ryegrass	F	4 (20)	82·17	0·003703	0·3042	0·444
		M	7 (23)	107·81	0·002470	0·2663	0·269
	Lucerne	F	4 (22)	97·16	0·002683	0·2607	0·568
		M	5 (21)	113·51	0·002309	0·2621	0·404

† Standard error values are not included as these may be misleading due to high correlations between estimates of parameter values. W_0 (kg) was estimated for the males as 19·33 (B), 23·73 (X) and 27·02 (S) and for the females as 15·59 (B), 18·66 (X) and 22·14 (S) across foods.
‡ As described in Table 2.
§ As described in Table 1.
‖ Number of lambs followed in parentheses by weeks of data.

Although there was no effect of food on efficiency, lambs on ryegrass grew more slowly and ate less food than lambs on lucerne or the choice diet. The higher protein content in lucerne (Ministry of Agriculture, Fisheries and Food, 1975) probably allows better rumen function and faster fermentation of the food (Nandra *et al*., 2000). As a consequence lambs on this food, and the choice, would have faster movement of food through the gut, higher intakes and higher growth rates such as those found here.

Tolkamp *et al*. (1998) suggested that ruminants had a preference for a particular level of ruminally degradable protein when given suitable choices. This is consistent with the lambs here showing a marked, but not complete, preference for lucerne over ryegrass. It was not expected that breed or sex would affect the proportion of ryegrass chosen at a particular degree of maturity. The proportion of ryegrass selected in the diet changed slowly with time (Figure 4), with lambs selecting higher proportions of ryegrass at later stages of maturity. This is in the expected direction since it has been found that animals choose progressively less of a higher protein food as their relative growth rate and thus protein requirements decline (Kyriazakis *et al*., 1993; Kyriazakis and Emmans, 1993; Kyriazakis and Oldham, 1993).

The effects of breed and sex on growth are as expected from differences in mature size, as explored by the Spillman analysis (Figure 5a and b). There was little difference between the Spillman curves for lambs on the two forages, although lambs on lucerne appear to grow to slightly heavier weights than lambs on ryegrass at the same levels of cumulative food intake. However there were no obvious differences in efficiency as indicated by the values of the (*A k*) parameter either between forages or breeds or sexes, which is consistent with the conclusions of the live performance results. The (*A k*) parameters for the two forages in this study are intermediate between those for the high quality food and the bulky food used by Lewis *et al*. (2004b).

The estimates of mature weight from the Spillman function were lower than expected being consistently about 0·86 of their prior estimate. Estimates of male mature weights were approximately 1·3 of female mature weights, in line with the estimates of Hammond (1932). Lewis *et al*. (2004b) also found the Spillman function produced low estimates of mature weights, although their estimates were even lower than those in this study. The fact that the data available only went to 0·65 mature weight will have contributed to this general underestimation of mature weight.

The estimates of heterosis in this study were lower than those reported by Lewis *et al*. (2004b) for the same breed combinations. The estimate of 0·08 for post weaning growth agrees with that of Nitter (1978) who gave a mean of 0·06 to 0·07 using estimates from 19 studies. We found no strong evidence of heterosis for carcass composition. Jakubec (1977) reviewed papers from several countries and concluded that heterosis effects on carcass traits are small and unimportant. Nitter (1978) used the data from seven studies to conclude that crossbred sheep showed no advantage over the

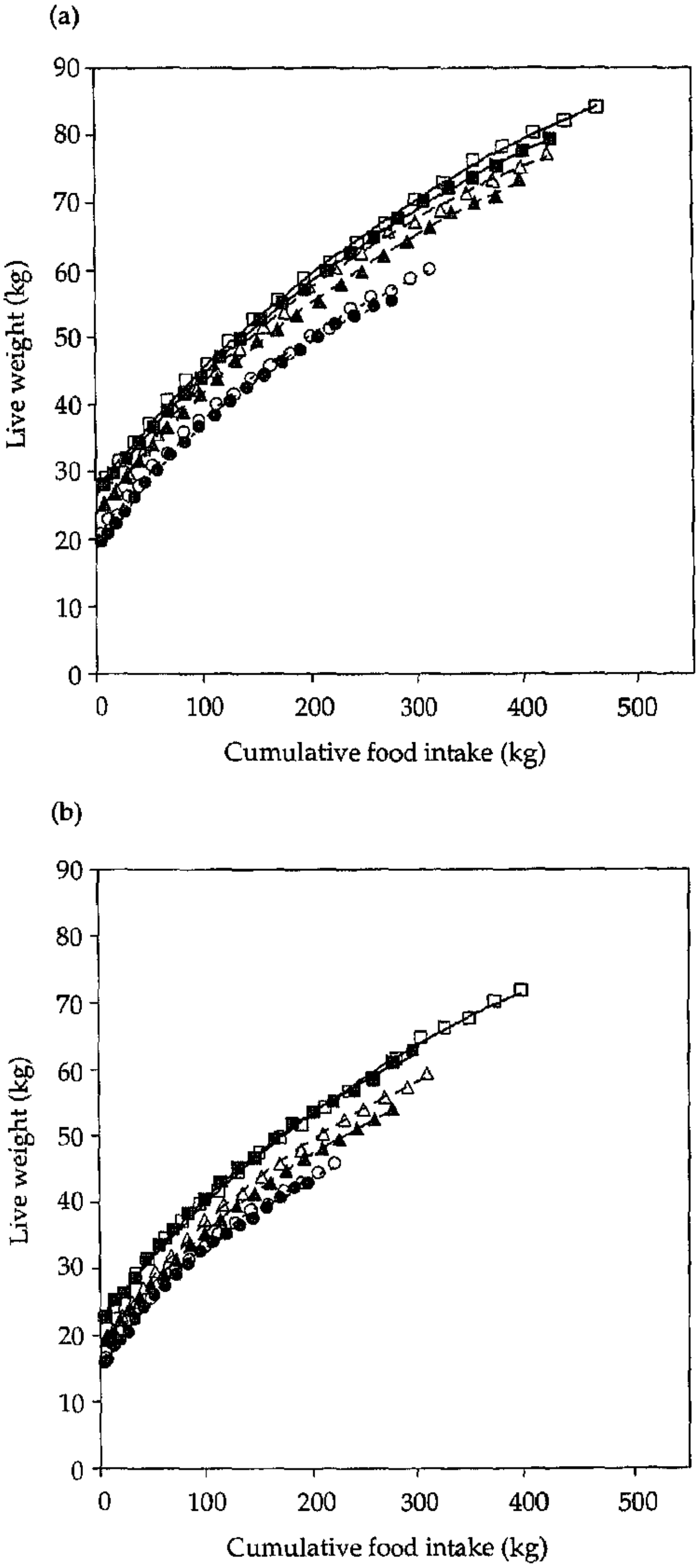

Figure 5 Live weight against cumulative food intake for (a) male and (b) female Suffolk (actual ■, predicted ——) and Scottish Blackface (actual ●, predicted ······) lambs, and for their cross (actual ▲, predicted - - - -), on ryegrass. The data for the same sex of Suffolk (actual □, predicted ——) and Scottish Blackface (actual O, predicted ······) lambs, and for cross (actual △, predicted - - - -), on lucerne are also shown.

pure parental breeds in carcass traits. Lee (1984) also found small and insignificant effects of heterosis on carcass traits in Scottish Blackface and Welsh Mountain sheep. Leymaster (2002) reached the same conclusions as in these studies in a recent review.

Lewis *et al.* (2004b), using sheep that were given concentrates of different quality, concluded that there were no important differences in carcass composition between the breeds used. The results reported here extend this conclusion to two dried forages and a choice feeding treatment. The three feeding treatments caused no differences in carcass composition.

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